DIATOMS OF OREGON CAVES NATIONAL MONUMENT, OREGON

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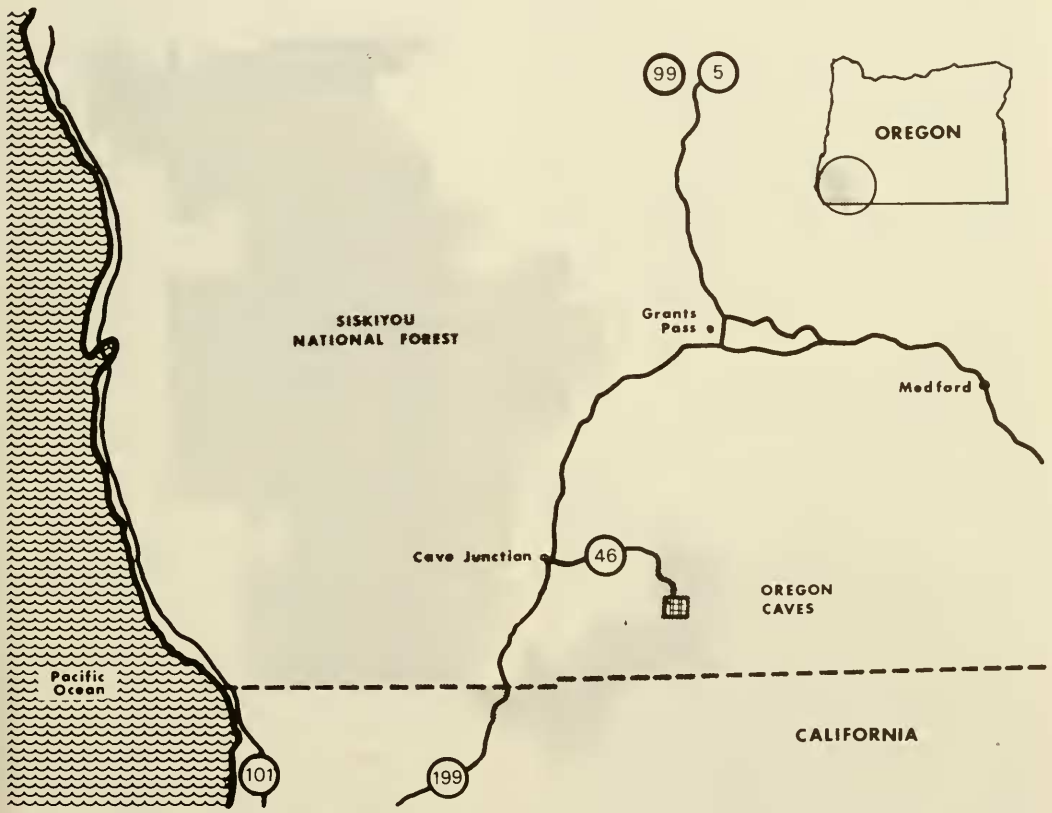
ABSTRACT.— The diatom flora of the Oregon Caves National Monument, Josephine Co., Oregon, was investigated. Diatoms were distributed throughout the cave system with abundance and species diversity depending upon moisture, light, availability of mineral nutrients, and proximity to cave openings. Twenty-six taxa were identified and described.

Oregon Caves National Monument is 32 km southeast of Cave Junction on Oregon State Highway 46, Josephine County, Oregon (Map 1). The combined length of passageways and rooms in the caves is approximately 1 km. The entrance of the caves is at an elevation of 1200 m within a natural transition zone between a lower elevation flora of mixed deciduous trees and shrubs and a higher elevation flora dominated by conifers.

The Oregon Caves are stratigraphically in a marble bed in the Applegate group. Applegate rocks are triassic in age and consist of interbedded sedimentary rocks and



Map 1. Oregon Caves National Monument is located in the Siskiyou National Forest, 32 kilometers southeast of Cave Junction, Oregon.

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volcanic ash and fragments (State of Oregon 1942). Shales, sandstones, and limestones of the Applegate group were metamorphosed and then uplifted to form part of the Klamath peneplane. Erosion of this peneplane formed the Klamath mountain system, which includes the Siskiyou Range and Oregon Caves. Cave formation in this system is similar to that of other localities, with extensive ground water erosion and associated deposition of calcium carbonate.

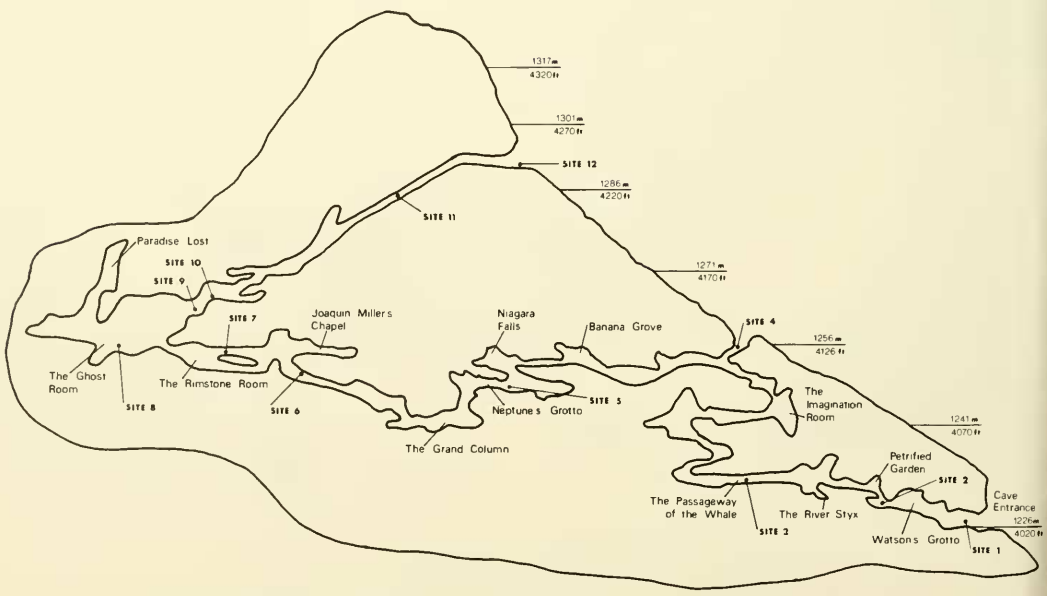
The caves were discovered by Elijah Davison in the fall of 1874. Nevertheless, it was not until 1909 that a tract of 195 hectares was set aside as Oregon Caves National Monument. Lighting in the caves was installed in 1932, which also marked the beginning of regular public visits.

Shortly after the lighting system was installed, the development of moss gametophytes and algal incrustations on and near formations adjacent to light fixtures was observed. The encroachment of these organisms onto formations in the caves has resulted in the permanent discoloration of some formations, with probable physical degradation in some cases. The present study was initiated to determine the species of algae resident in the caves in order to provide baseline data for establishing management techniques for controlling algal and moss growth on cave formations. This paper deals with the diatom species in the Oregon Caves system, with observations and comments on diatom distribution patterns.

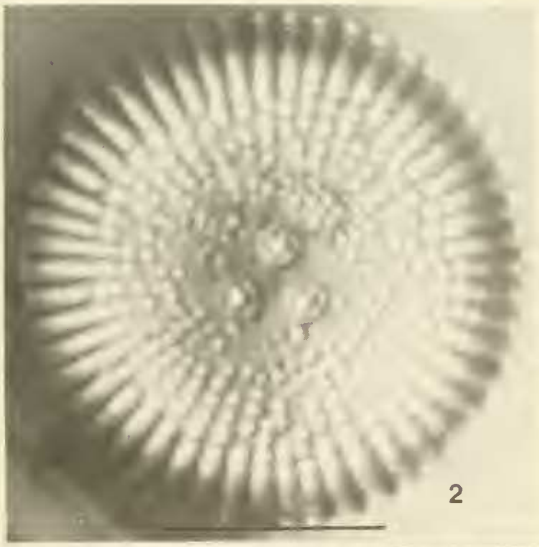
Materials and Methods

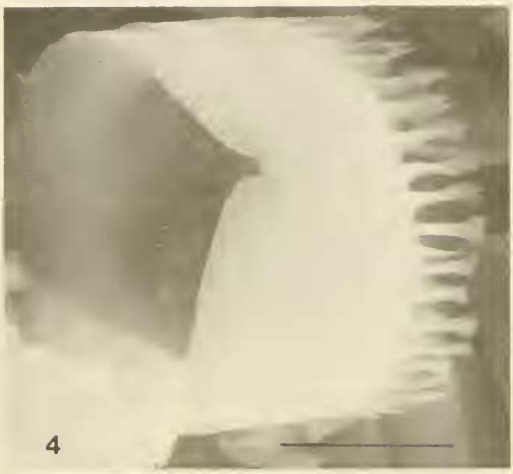
One composite sample was collected from each of 12 sites located at regular intervals throughout the rooms and passageways of the cave on 28 April 1978. Samples were collected under sterile conditions, with presterilized instruments and collecting vials. Most samples consisted of scrapings from algal-moss associations adjacent to light fixtures. However, some scrapings were made of dry incrusted algae on cave formations and of mucilaginous material from several seep walls.

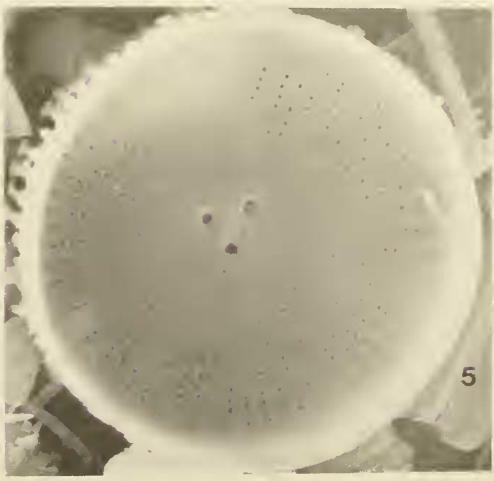
The 12 collecting sites (Map 2) were designated as follows: No. 1, scrapings from wall of cave entrance; No. 2, scrapings from wall and floor near light between Watson's Grotto and Petrified Gardens; No. 3, scrapings from wall in passageway of the Whale; No. 4, scrapings from wall and floor of the 110 exit; No. 5, scrapings from wall near light in passageway between Throne Room and Neptune's Grotto; No. 6, scrapings from Touching Post; No. 7, scrapings from wall



Map. 2. Twelve collection sites (represented by black dots) were established at regular intervals throughout the 1 km length of the cavern system.







Figs. 1–5. *Melosira roeseana*: 1, girdle view, light micrograph; 2, valve view, light micrograph; 3, girdle view, scanning electron micrograph (SEM); 4, oblique girdle view, SEM; 5, inner view of valve, SEM. All scales equal to 10 μm.

and floor in Rhinestone Room; No. 8, scrapings from wall near light in Ghost Room; No. 9, scraping of slime accumulated on stair rail between Ghost Room and Wedding Cake Room; No. 10, scrapings from wall in Wedding Cake Room; No. 11, scrapings from wall and floor of exit tunnel; No. 12, scrapings from face of exit.

Wet mounts of each sample were prepared in order to determine whether or not viable diatoms were present. Living specimens were observed from all samples except sample No. 9. In several samples large numbers of living individuals were observed.

Standard methods for preparing diatom slides were used (St. Clair and Rushforth 1976). Portions of each sample were boiled in concentrated nitric acid and washed with distilled water. A small portion of the solution containing cleaned diatom frustules was dried on cover slips that were then mounted in Naphrax diatom mountant.

Identifications were made using a Zeiss RA microscope equipped with Normarski interference phase-contrast accessories. Photomicrographs were taken of each species using Nikon AFM photomicrographic accessories.

A second subsample of cleaned frustules was mounted on scanning electron microscope stubs. These were studied in an Amray 1000 scanning electron microscope. Photomicrographs were taken of each species observed.

RESULTS

Ten genera including 26 taxa were identified during this study (Table 1). These diatoms, described and discussed below, were identified from various locations throughout the rooms and connecting passageways of the Oregon Caves. A reference to a complete description is given for each species.

Melosira

***Melosira roeseana* Rabenhorst** (Figs. 1–5). Diameter 19–33 μm; striae 7–10 in 10 μm; punctae distinct, 3–4 prominent punctae in center of valve (Hustedt 1930:93). It was common at the passageway between Watson's Grotto and the Petrified Gardens (Site 2), 110 exit (Site 4), exit tunnel (Site 11), and the face of the exit (Site 12).

TABLE 1. Phylogenetic list of diatoms (Division Basillariophyta, Class Bassilariophyceae) collected from the Oregon Caves National Monument.

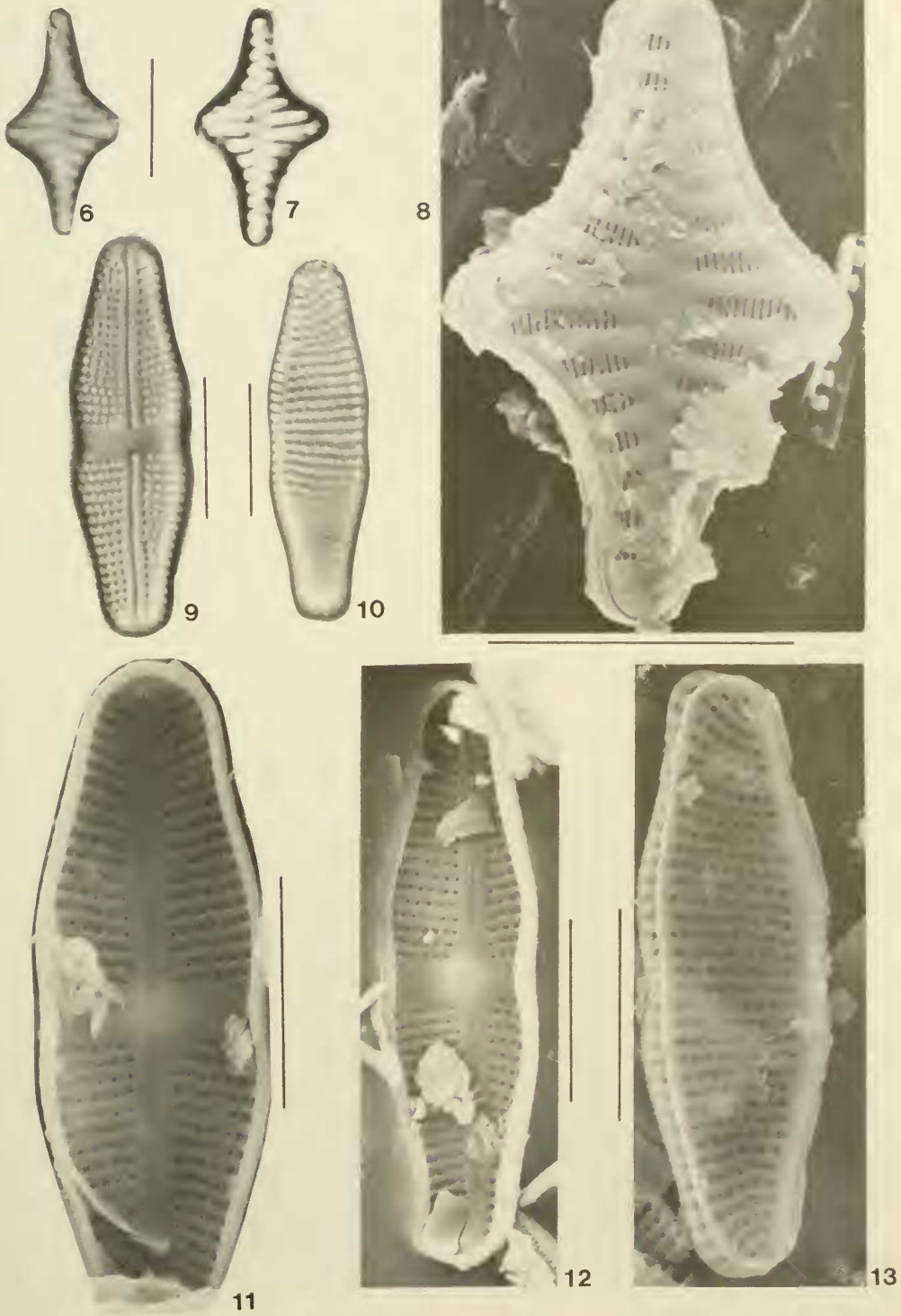
Order Rhizosoleniales
  Family Coscinodiscaceae
    Melosira roeseana Rabenhorst
Order Fragilariales
  Family Fragilariaceae
    Fragilaria construens (Ehr.) Grunow
Order Achnanthales
  Family Achnanthaceae
    Achnanthes coarctata (Breb. in W. Sm.) Grunow
    Achnanthes exigua Grunow
    Achnanthes exigua var. *heterovalva* Krasske
    Achnanthes lanceolata (Breb.) Grunow
    Achnanthes microcephala (Kutz.) Grunow
    Achnanthes minutissima Kutzing
    Achnanthes montana Krasske
Order Naviculales
  Family Naviculaceae
    Diploneis oblongella (Naeg. ex Kutz.) Ross
    Navicula brekkaensis Petersen
    Navicula contenta f. *biceps* Arnott
    Navicula cryptocephala var. *veneta* (Kutz.) Rabenhorst
    Navicula gallica var. *montana* Bahls
    Navicula insociabilis Krasske
    Navicula minima Grunow
    Navicula pelliculosa (Breb. ex Kutz) Hilse
    Navicula perpusilla (Kutz.) Grunow
    Navicula pupula var. *rectangularis* (Greg.) Grunow
    Navicula secura Patrick
    Pinnularia sp.
  Family Cymbellaceae
    Cymbella minuta var. *silesiaca* (Bleisch ex. Rabh.) Reimer
    Amphora perpusilla (Grun.) Grunow
Order Bacillariales
  Family Nitzschiaceae
    Hantzschia amphioxys (Ehr.) Grunow
    Nitzschia linearis (Agardh) Wm. Smith
    Nitzschia palcacea Grunow

Fragilaria

***Fragilaria construens* (Ehr.) Grunow** (Figs. 6–8). Length 19–20 μm; width 9–12 μm; striae 10–12 in 10 μm (Patrick and Reimer 1966:125). It was found at: tunnel between Watson's Grotto and the Petrified Gardens (Site 2), passageway between Throne Room and Neptune's Grotto (Site 5), and the Wedding Cake Room (Site 10).

Achnanthes

***Achnanthes coarctata* (Breb. *in* W. Sm.) Grunow** (Figs. 9–13). Length 32–34 μm; width 9–10 μm; rapheless valve striae 12–14 in 10 μm; raphe valve striae 12–16 in 10 μm



Figs. 6–13. Diatom spp.: 6–7, *Fragilaria construens* valve views, light micrographs; 8, *Fragilaria construens* valve view, SEM; 9, *Achnanthes coarctata* raphe valve view, light micrograph; 10, *Achnanthes coarctata* nonraphe valve, light micrograph; 11–12, *Achnanthes coarctata* raphe valve views, SEM; 13, *Achnanthes coarctata* nonraphe valve view, SEM. All scales equal to 10 μm.

(Patrick and Reimer 1966:277). It was found only at the exit tunnel (Site 11).

Achnanthes exigua **Grunow** (Figs. 14–17; 21). Length 12–15 μm; width 5–6 μm; rapheless valve striae 20–24 in 10 μm; raphe valve striae 24–28 in 10 μm (Patrick and Reimer 1966:257). One of most common species in this study, it was identified from the following sites: tunnel between Watson's Grotto and Petrified Gardens (Site 2), Passageway of the Whale (Site 3), 110 exit (Site 4), passageway between the Throne Room and Neptune's Grotto (Site 5), the Rhinestone Room (Site 7), the Ghost Room (Site 8), the Wedding Cake Room (Site 10), the exit tunnel (Site 11), and the face of the exit (Site 12).

Achnanthes exigua **var.** *heterovalva* **Krasske** (Figs. 18–20). Length 7–10 μm; width 4–5 μm; raphe and rapheless valve striae 25–27 in 10 μm (Patrick and Reimer 1966:258). It was identified from the following sites: Passageway of the Whale (Site 3), passageway between the Throne Room and Neptune's Grotto (Site 5), the Rhinestone Room (Site 7), the Wedding Cake Room (Site 10), and the exit tunnel (Site 11).

Achnanthes lanceolata **(Breb.) Grunow** (Figs. 22–29). Length 9–15 μm; width 4–5 μm; rapheless valve striae 14–16 in 10 μm; raphe valve striae 12–14 in 10 μm (Patrick and Reimer 1966:269). It was collected from the following sites: tunnel between Watson's Grotto and the Petrified Gardens (Site 2), Passageway of the Whale (Site 3), 110 Exit (Site 4), passageway between the Throne Room and Neptune's Grotto (Site 5), the Wedding Cake Room (Site 10), and the exit tunnel (Site 11).

Achnanthes microcephala **(Kutz.) Grunow** (Fig. 30). Length 7–8 μm; width 2–3 μm; striae about 30 in 10 μm on both valves, often not resolved (Patrick and Reimer 1966:250). Collected from the Passageway of the Whale (Site 3).

Achnanthes minutissima **Kutzing** (Figs. 31–32). Length 9–12 μm; width 2–3 μm; striae 30–32 in 10 μm on both valves (Patrick and Reimer, 1966:253). Common at all sites in the cave system except for Site 9, and the face of the exit (Site 12).

Achnanthes montana **Krasske** (Figs. 33–34, 40–41). Length 10–12 μm; width 5–6 μm; striae 18–20 in 10 μm on both valves (Hustedt 1930:204). It was identified from the following samples: passageway between Watson's Grotto and the Petrified Gardens (Site 2), Passageway of the Whale (Site 3), 110 exit (Site 4), passageway between the Throne Room and Neptune's Grotto (Site 5), and the Rhinestone Room (Site 7).

Diploneis

***Diploneis oblongella* (Naeg. *ex* Kutz.) Ross** (Figs. 36–39). Length 10–26μm; width 7–8 μm; costae 14–20 in 10 μm (Patrick and Reimer 1960:413). Identified from two sites, the Wedding Cake Room (Site 10) and the exit tunnel (Site 11).

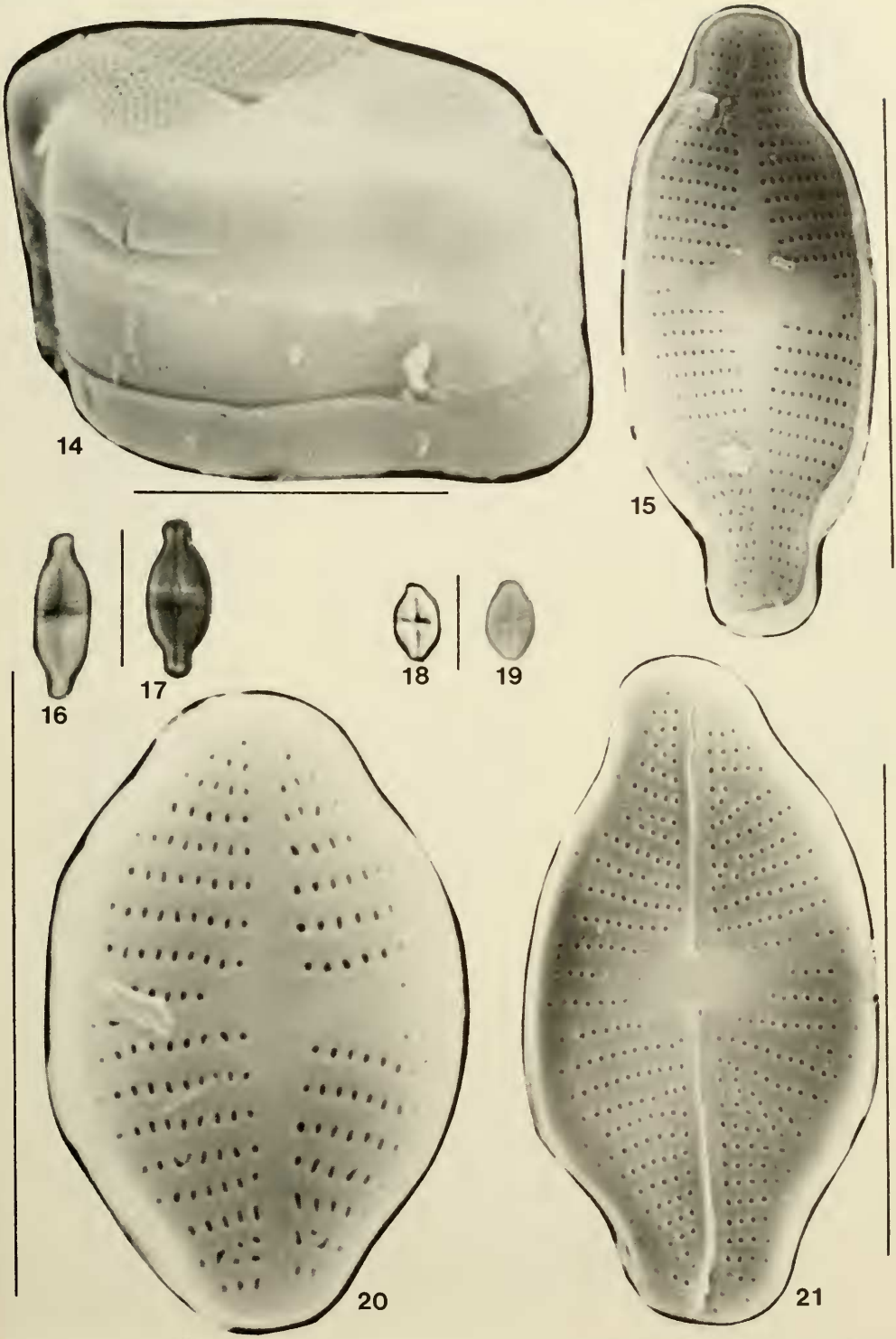
Navicula

***Navicula brekkaensis* J. B. Petersen** (Figs. 55–57). Length 9–15 μm; width 2–3 μm; striae about 35 in 10 μm (Hustedt 1960–1966:221). Taken in the passageway between the Throne Room and Neptune's Grotto (Site 5).

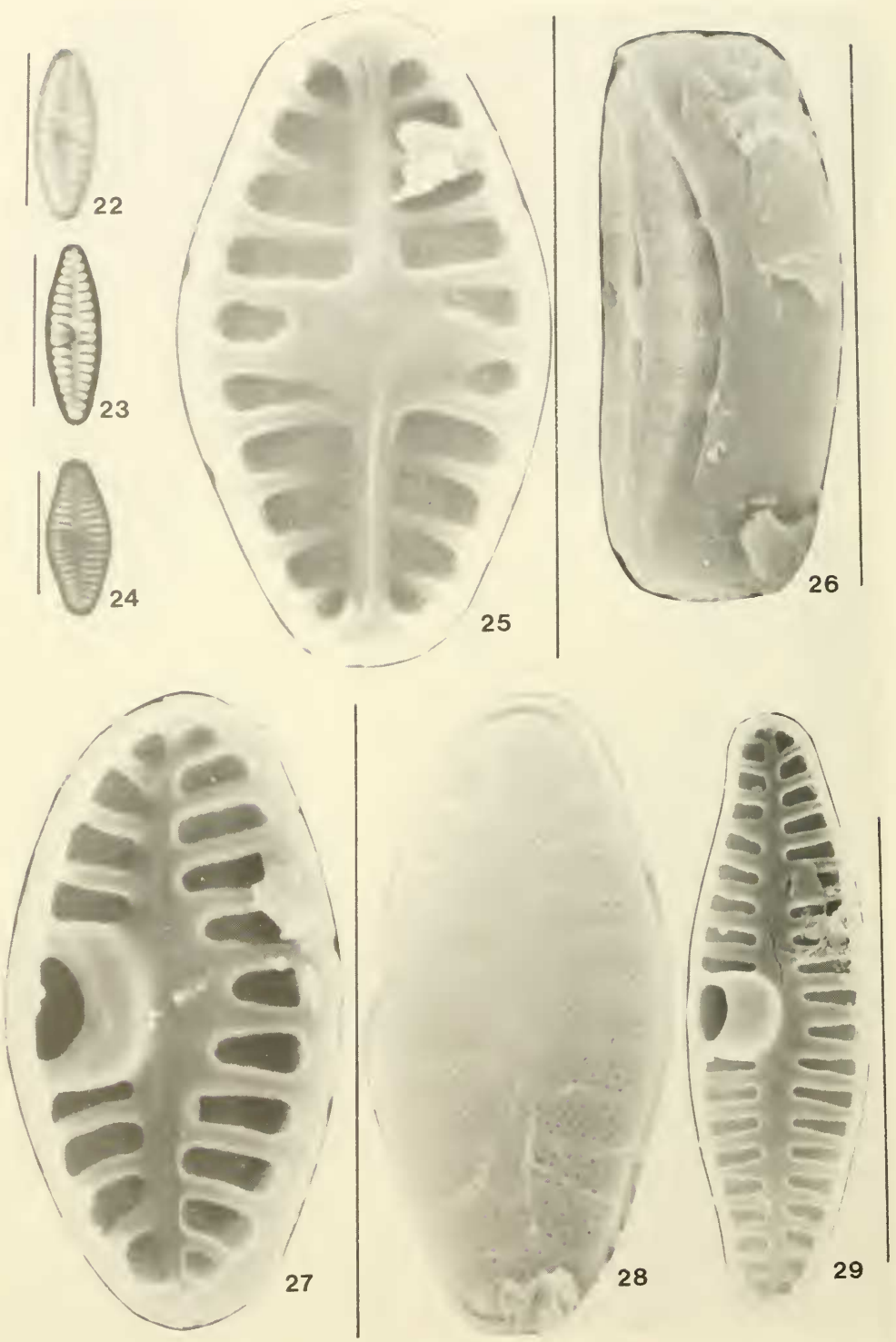
Navicula contenta **f.** *biceps* **Arnott** (Figs. 62–68). Length 10–16 μm; width 3–4 μm; striae 33–36 in 10 μm (Hudstedt 1930:277). Common throughout the cave system and at all sites except for the passageway between the Throne Room and Neptune's Grotto (Site 5), the Rhinestone Room (Site 7), Site 9 and the Wedding Cake Room (Site 10).

Navicula cryptocephala **var.** *veneta* **(Kutz.) Rabenhorst** (Figs. 59–61). Length 20–25 μm; width 5–6 μm; striae 15–18 in 10 μm (Patrick and Reimer 1966:504). Rare from samples collected in the Wedding Cake Room (Site 10).

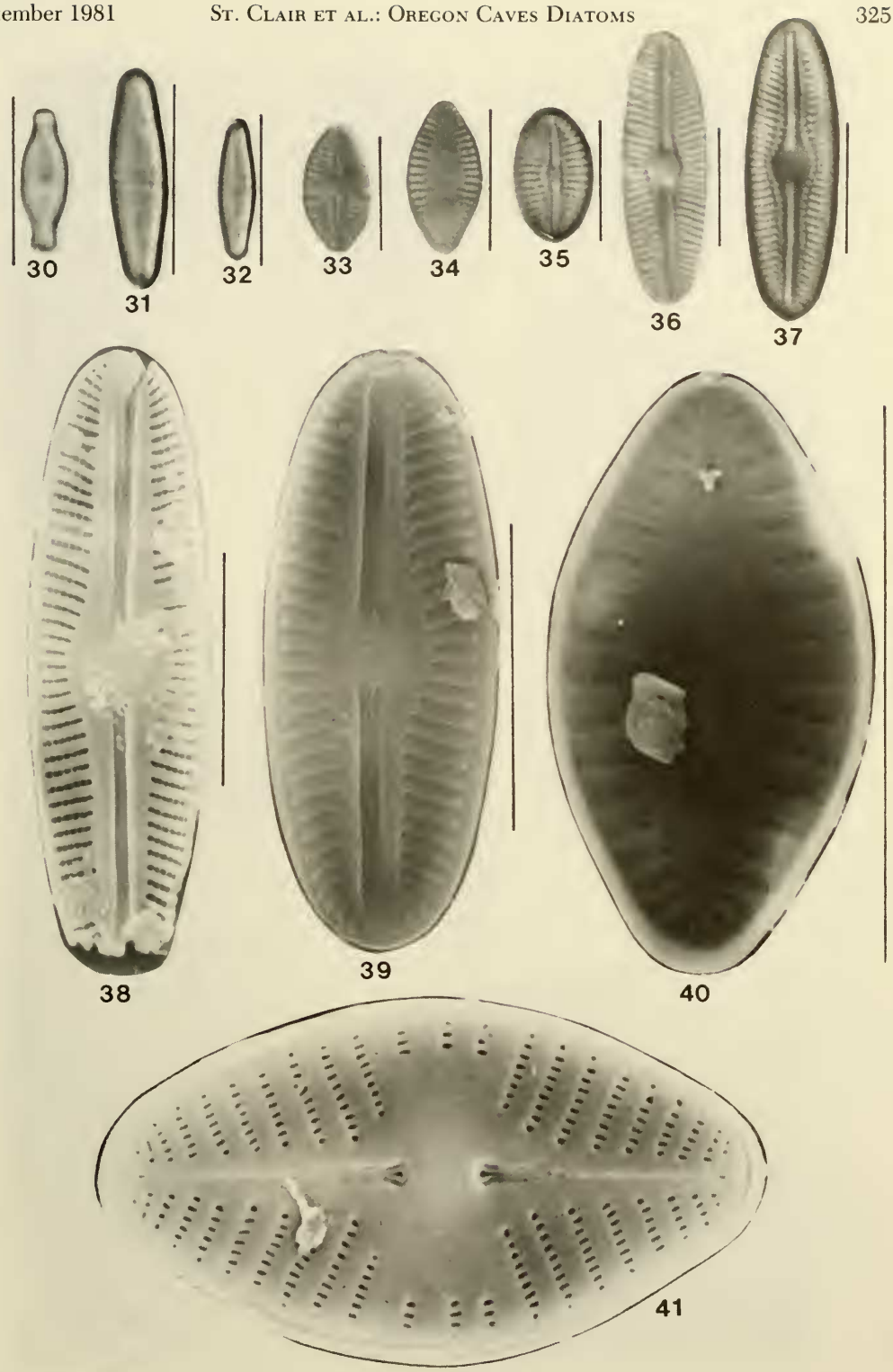
Navicula gallica **var.** *montana* **Bahls** (Figs. 42–48, 53). Length 12–19 μm; width 3–4 μm; striae 28–38 in 10 μm (Bahls 1981:14). At all sites except Site 9. This taxon was recently named from specimens collected from Lewis and Clark Caverns, Montana, by Loren Bahls (1981). We have used the name based on the lanceolate axial area and the length. Some of our specimens, however, have finer striae than either the nominate or variety of this taxon, ranging into the striae range of *N. fragilarioides*. Even so, the striae range appeared to be continuous and we chose to place our specimens in a single taxon.



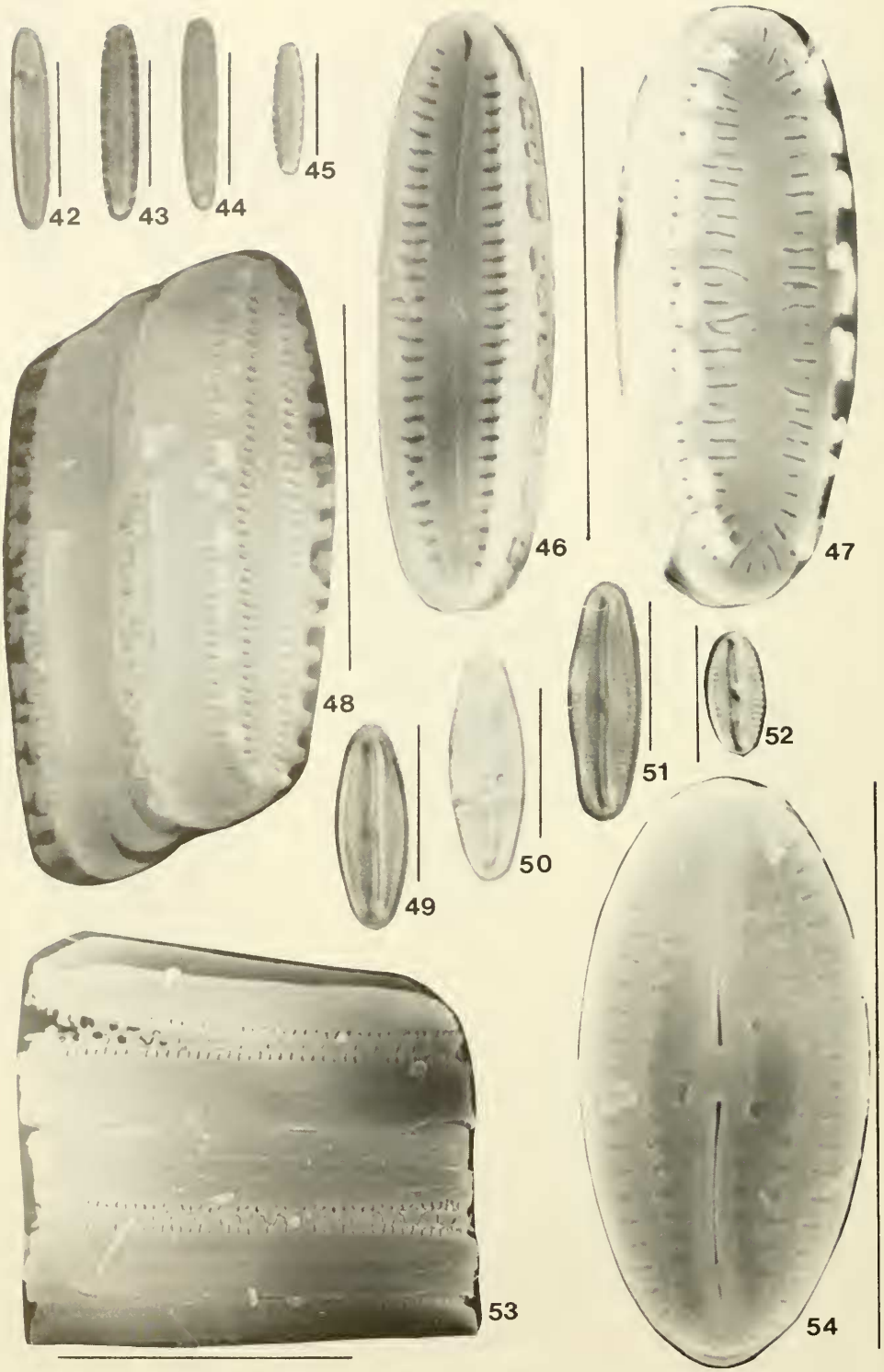
Figs. 14–21. *Achnanthes* spp.: 14, *Achnanthes exigua* oblique view of raphe valve, SEM; 15, *Achnanthes exigua* nonraphe valve, SEM; 16, *Achnanthes exigua* nonraphe valve, light micrograph; 17, *Achnanthes exigua* raphe valve, light micrograph; 18–19, *Achnanthes exigua* var. *heterovalva* nonraphe valve views, light micrographs; 20, *Achnanthes exigua* var. *heterovalva* nonraphe valve, SEM; 21, *Achnanthes exigua* raphe valve, SEM. All scales equal to 10 μm.



Figs. 22–29. *Achnanthes lanceolata*: 22, raphe valve, light micrograph; 23–24, nonraphe valves, light micrographs; 25, inner view of raphe valve, SEM; 26, oblique view of frustule, SEM; 27, inner view of nonraphe valve, SEM; 28, outer view of nonraphe valve, SEM; 29, inner view of nonraphe valve, SEM. All scales equal to 10 μm.



Figs. 30–41. *Achnanthes* spp. and *Diploneis* sp.: 30, *A. microcephala* raphe valve, light micrograph; 31–32, *A. minutissima* raphe valves, light micrographs; 33, *A. montana* raphe valve, light micrograph; 34, *A. montana* nonraphe valve, light micrograph; 35–37, *D. oblongella* valve views, light micrographs; 38–39, *D. oblongella* valve views, SEM; 40, *A. montana* nonraphe valve, SEM; 41, *A. montana* raphe valve, SEM. All scales equal to 10 μm.



Figs. 42–54. *Navicula* spp.: 42–45, *N. gallica* var. *montana* valve views, light micrographs; 46–47, *N. gallica* var. *montana* valve views, SEM; 48, *N. gallica* var. *montana* oblique view showing two frustules, SEM; 49–52, *N. insociabilis* valve views, light micrographs; 53, *N. gallica* var. *montana* girdle view showing several joined frustules, SEM; 54, *N. insociabilis* valve view, SEM. All scales equal to 10 μm.

Navicula insociabilis **Krasske** (Figs. 49–52, 54). Length 9–16 μm; width 5–6 μm; striae 23–26 in 10 μm (Hustedt 1960–1966:181). Collected from the tunnel between Watson's Grotto and the Petrified Gardens (Site 2), the 110 Exit (Site 4), the Wedding Cake Room (Site 10), and the exit tunnel (Site 11).

Navicula minima **Grunow** (Figs. 71–72). Length 9–11 μm; width 4–5 μm; striae 24–30 in 10 μm (Patrick and Reimer 1966:488). Collected from the tunnel between Watson's Grotto and the Petrified Gardens (Site 2) and the 110 Exit Site (Site 4).

Navicula pelliculosa **(Breb. *ex* Kutz.) Hilse** (Figs. 73–74, 80). Length 5–11 μm; width 3 μm; striae unresolved (Patrick and Reimer 1966:484). Identified from the Passageway of the Whale (Site 3) and the Touching Post (Site 6).

Navicula perpusilla **(Kutz.) Grunow** (Fig. 69–70, 75–76). Length 9–11 μm; width 3–5 μm; striae 31–33 in 10 μm (Patrick and Reimer 1966:478). Identified from the entrance (Site 1), the tunnel between Watson's Grotto and the Petrified Gardens (Site 2), the 110 Exit (Site 4), and the Touching Post (Site 6).

Navicula pupula **var. *rectangularis* (Greg.) Grunow** (Fig. 58). Length 25 μm; width 7 μm; striae 14–15 in 10 μm (Patrick and Reimer 1966:497). Collected only from the face of the exit (Site 12).

Navicula secura **Patrick** (Figs. 77–79, 81–82). Length 10–14 μm; width 3–4 μm; striae 30–38 in 10 μm (Patrick and Reimer 1966:490). Collected from the entrance (Site 1), the tunnel between Watson's Grotto and the Petrified Gardens (Site 2), the Passageway of the Whale (Site 3), the 110 Exit (Site 4), and the passageway between the Throne Room and Neptune's Grotto (Site 5). Several of our specimens have somewhat coarser striae than those described by Patrick (1959).

Pinnularia

Pinnularia sp. 1 (Figs. 83–87). Valve 23–30 μm long by 4–5 μm wide, linear to slightly linear-elliptical; apices rounded to slightly rostrate; raphe linear, simple, proximal ends curved in same direction; axial area narrow, becoming broader near the central area; central area a broad transverse fascia; striae radiate, becoming convergent toward apices, 16–28 in 10 μm. Collected from the passageway between the Throne Room and Neptune's Grotto (Site 5), the Wedding Cake Room (Site 10), and the exit tunnel (Site 11). This species was also collected in the Timpanogos Cave System, Utah Co., Utah, and at that time was identified as *Pinnularia intermedia* (Lagerst) Cleve. The striae count, however, is significantly finer in our specimens than in descriptions for *P. intermedia*.

Cymbella

Cymbella minuta **var. *silesiaca* (Bleisch ex. Rabh.) Reimer** (Figs. 88–89). Length 20–22 μm; width 5–6 μm; dorsal striae 14 in 10 μm; ventral striae 14–18 in 10 μm (Patrick and Reimer 1975:49). Identified from the tunnel between Watson's Grotto and the Petrified Gardens (Site 2) and the Wedding Cake Room (Site 10).

Amphora

Amphora perpusilla **(Grun.) Grunow** (Fig. 90). Length 9–12 μm; width 3 μm; striae 16–17 in 10 μm (Patrick and Reimer 1975:70). Collected only from the passageway between the Throne Room and Neptune's Grotto (Site 5).

Hantzschia

Hantzschia amphioxys **(Ehr.) Grunow** (Figs. 94–95). Length 55–64 μm; width 6–7 μm; fibulae 7–9 in 10 μm; striae 24–28 in 10 μm (Hustedt 1930:393). Collected from the exit tunnel (Site 11) and the face of the exit (Site 12).

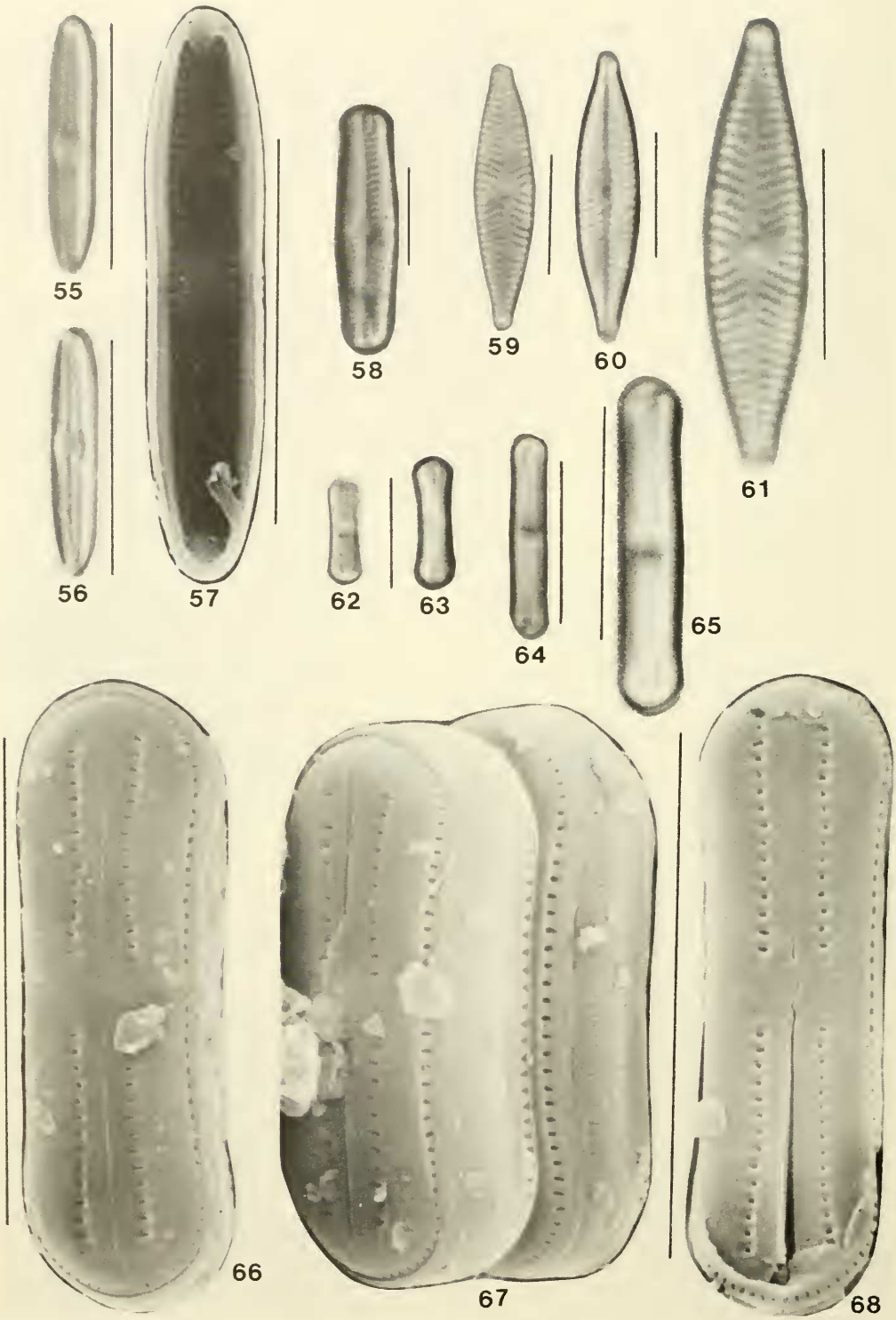
Nitzschia

Nitzschia linearis **(Agardh) Wm. Smith** (Figs. 91–93). Length 75–78 μm; width 5–6 μm; fibulae 8–12 in 10 μm; striae 28–32 in 10 μm (Hustedt 1930:409). Collected from the exit tunnel (Site 11) only.

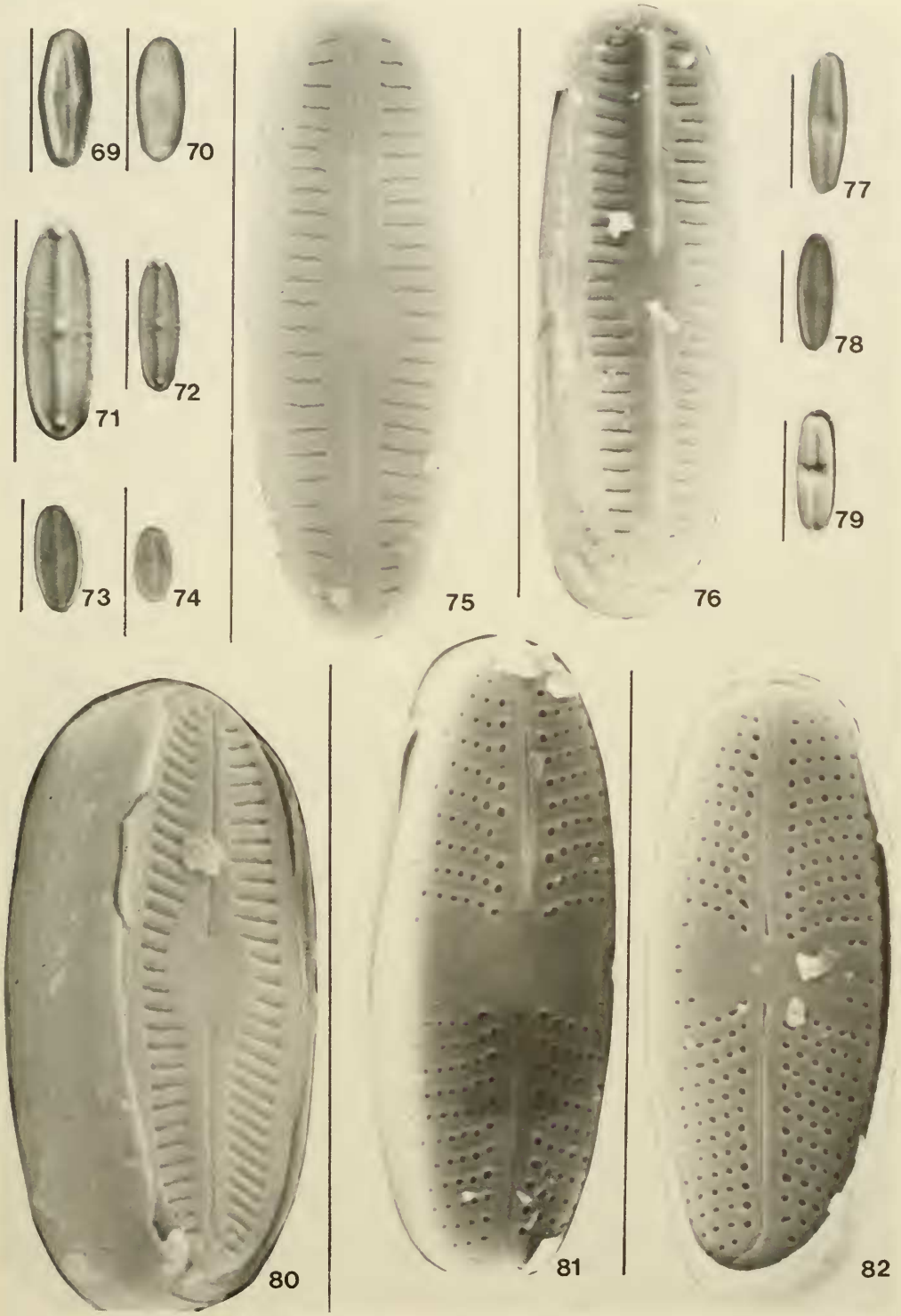
Nitzschia paleacea **Grunow** (Figs. 96–97). Length 23–38 μm; width 2–4 μm; fibulae 9–10 in 10 μm; striae unresolved (Hustedt 1930:416). Collected only from the passageway between the Throne Room and Neptune's Grotto (Site 5).

Discussion

Distribution and relative abundance data for all diatom species collected are summarized in Table 2. Distribution of species in



Figs. 55–68. *Navicula* spp.: 55–56, *N. brekkaensis* valve views, light micrographs; 57, *N. brekkaensis* valve view, SEM; 58, *N. pupula* var. *rectangularis* valve view, light micrograph; 59–61, *N. cryptocephala* var. *veneta* valve views, light micrographs; 62–65, *N. contenta* f. *biceps* valve views, light micrographs; 66, 68, *N. contenta* f. *biceps* valve views, SEM; 67, *N. contenta* f. *biceps* oblique view of two frustules, SEM. All scales equal to 10 μm.



Figs. 69–82. *Navicula* spp.: 69–70, *N. perpusilla* valve views, light micrographs; 71–72, *N. minima* valve views, light micrographs; 73–74, *N. pelliculosa* valve views, light micrographs; 75–76, *N. perpusilla* valve views, SEM; 77–79, *N. secura* valve views, light micrographs; 80, *N. pelliculosa* oblique valve view, SEM; 81–82, *N. secura* valve views, SEM. All scales equal to 10 μm.

the Oregon Caves system is apparently determined by several factors, especially moisture, light, availability of mineral nutrients, and proximity of sites to cave openings. The accumulation of algal material is most prolific in areas immediately adjacent to incandescent light fixtures. Formations highlighted with incandescent lights and having significant amounts of moisture seepage demonstrate a well-developed algal community.

Dry sites (such as sites 1, 6, 7, 8, and 12) were relatively low in species diversity, with an average of 5 species per site. Sites 2, 3, 4, 5, 10, and 11, where moisture accumulation and seepage is continuous, had an average of 11.7 species per site. Generally, those species that occurred at dry sites were ubiquitous and occurred throughout the system. Besides being wet, sites 2, 3, 4, 5, 10, and 11 are all located in close proximity to one of three cave openings, the entrance, the 110 exit, or the principal exit. Thus, elevated moisture and the close proximity of openings in the cave increase the diversity of diatom species. Sites 1 and 12 are the entrance and main exit to the cave, respectively. Both these sites are in effect exterior to the cave proper and, consequently, the flora at these sites is different from the characteristic cave flora. Several environmental factors vary significantly at these two sites, including no direct exposure to incandescent light, reduced moisture, and seasonal temperature and light fluctuations.

Diversity of species was low at several of the sites, but the actual number of organisms was high for all sites. This is likely attributable to the relatively consistent environmental conditions and daily exposure to incandescent lights throughout the year.

TABLE 2. Diatom distribution in the Oregon Caves National Monument. A = abundant, C = common, R = rare.

Diatom species	Site 1 Entrance	Site 2 Between Watson's Grotto Gardens	Site 3 Passageway of the Whale	Site 4 110 exit	Site 5 Passageway between Throne Room and Neptune's Grotto
Melosira roeseana		R		R	
Fragilaria construens		R			C
Achnanthes coarctata					
Achnanthes exigua		C	C	C	A
Achnanthes exigua var. *heterovalva*			A		A
Achnanthes lanceolata		R	R	R	C–A
Achnanthes microcephala			R		
Achnanthes minutissima	C	C	C	C	C
Achnanthes montana		C	C–A	R–C	C
Diploneis oblongella					
Navicula brekkaensis					R
Navicula contenta f. *biceps*	C	A	R–C	C	
Navicula cryptocephala var. *veneta*					
Navicula gallica var. *montana*	A	A	C	C	R–C
Navicula insociabilis		R–C		R	
Navicula minima		R		R	
Navicula pelliculosa			R		
Navicula perpusilla	R–C	C		R	
Navicula pupula var. *rectangularis*					
Navicula secura	C	C	C	A	C
Pinnularia sp.					R
Cymbella minuta var. *silesiaca*		R			
Amphora perpusilla					R
Hantzschia amphioxys					
Nitzschia linearis					
Nitzschia paleacea					R
Total species per site	5	13	10	11	12

Diatom species tend to aggregate around light fixtures, particularly in areas where there is a significant buildup of soil or a mat of moss gametophytes. Diatoms generally did not occur on $CaCO_3$ formations unless there was a substantial accumulation of soil or organic debris. Contrary to the above-mentioned observation, associations of green and blue green algae on $CaCO_3$ formations were common. This feature of diatom substrate preference is likely related to the paucity of certain mineral nutrients on the $CaCO_3$ substrates.

Literature Cited

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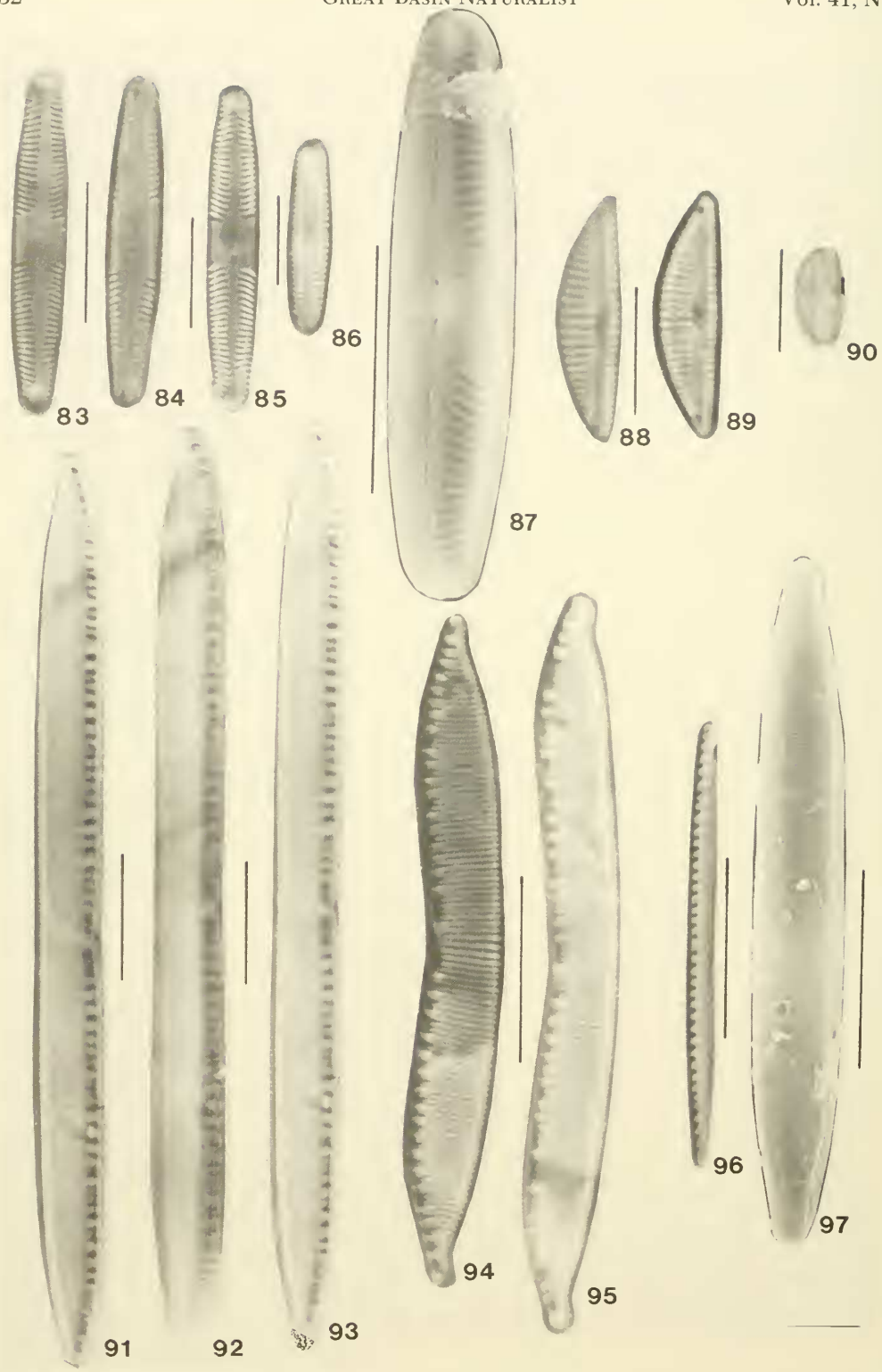
Table 2 continued.

Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Touching Post	Rhinestone Room	Ghost Room	Slime on stair rail	Wedding Cake Room	Exit tunnel	Face of exit
					A	A
				R		
					C	
	C	R		C	C	R
	C			R	R	
				R-C	R	
C	R	R-C		C	C	
	R					
				A	C	
R-C		R			C	A
				C		
C	A	C		A	A	R
				R	R	
R-C						
R-C						
						R
				C-A	C	
				R		
				R	R	
				R		
5	5	4	0	13	12	5



Figs. 83–97. Diatom spp.: 83–86. *Pinnularia* sp. valve views, light micrographs; 87, *Pinnularia* sp. oblique valve view, SEM; 88–89, *Cymbella minuta* var. *silesiaca* valve views, light micrographs; 90, *Amphora perpusilla* valve view, light micrograph; 91–93, *Nitzschia linearis* valve views, light micrographs; 94–95, *Hantzschia amphioxys* valve views, light micrographs; 96, *Nitzschia paleacea* valve view, light micrograph; 97, *Nitzschia paleacea* valve view, SEM. All scales equal to 10 μm.